High Emission Density Thermionic Cathode

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High Emission Density Thermionic Cathode

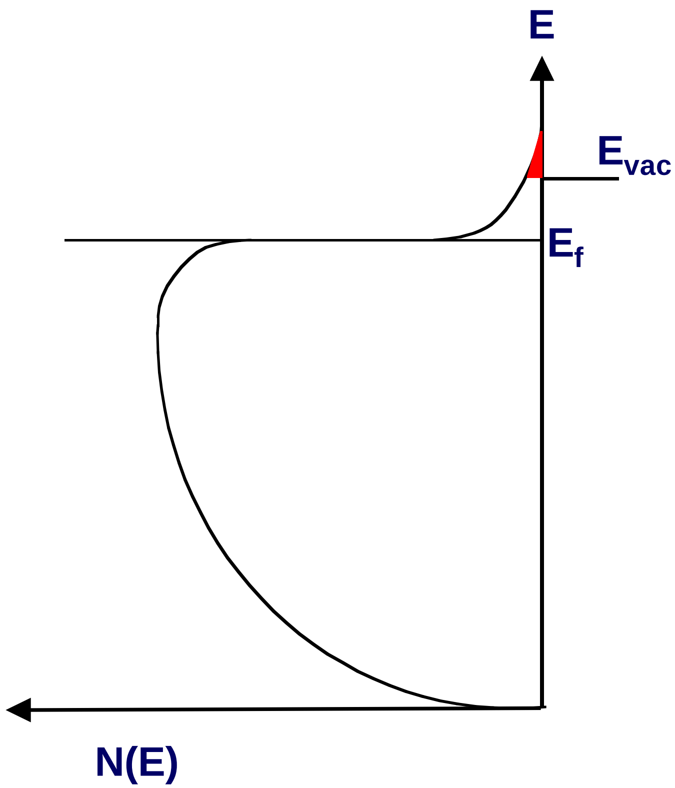
- Historical development
- Properties of various cathodes
  - Emission capability
  - Operation: activation and poisoning
  - Life

OUTLINE

1. Work function : figure of merit
2. W and thoriated W cathodes
3. Oxide cathodes
4. Dispenser cathodes
5. Scandate cathodes

Work Function

Electron energy distribution in a metal



$$\boxed{\Phi = E_{vac} - E_f}$$

Richardson equation

$$J = AT^2 e^{-\Phi/\kappa T}$$

$$A = 120\ A/cm^2\ K$$

Φ (eV)	T (K)	J (A/cm^2)
4.6	2600	1
4.6	2500	0. 4
3.6	2500	41

Φ about 4.6 eV for W

Thoriated Tungsten

Thoriated Tungten (Th-W):

A small percentage of thoria in W .

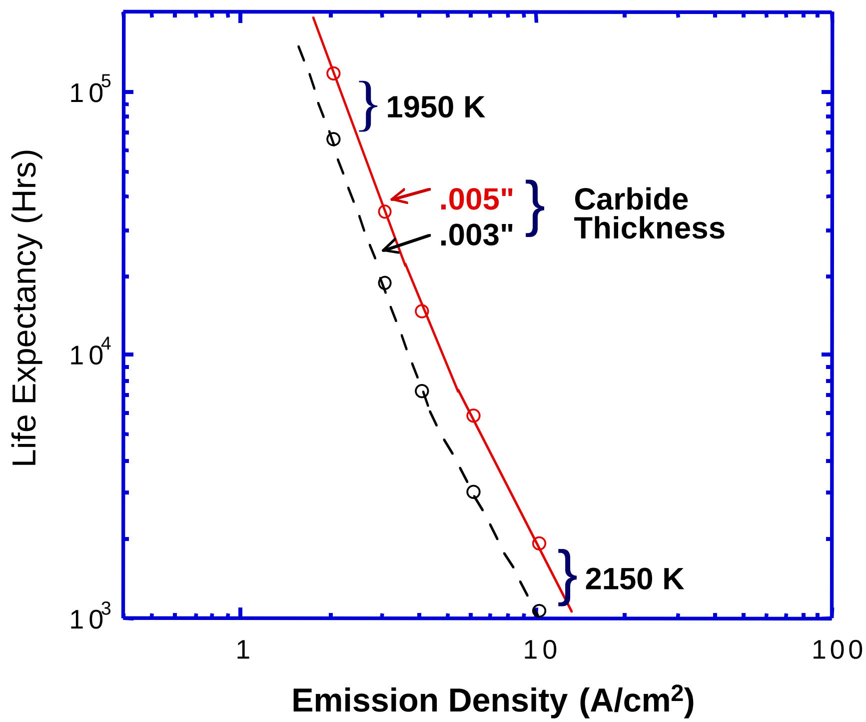
Thorium diffuses to the surface of the tungsten, and reduces the work function.

Carburization reduces the evaporation rate of the thorium.

	A_o	Φ_o
Th-W	4	2.65

Reference data for engineers: Radio,Electronics, Computer & Communications 8th Edition, p16-3, ed. M.Van Valkenburg, Newnes Press, Boston MA, 1993

Life Expectancy for a Switch Tube with a Th-W Cathode



T.E.Yingst, et al, Proc. IEEE, March 1973

The Relation of Φ_o to Φ

Work function determination using Richarson plot yields Φ_o.

Φ_o is the temperature-independent part of Φ.

i.e. $\Phi = \Phi_o + c\,T$

Re-write the Richardson equation,

$$J = AT^2 \exp(-\Phi_o + c\,T)/\kappa T$$

$$= [A \exp(-c/\kappa)]\, T^2 \exp(-\Phi_o/\kappa T)$$

For Th-W:

$\Phi_o = 2.65$

$A_o = [120 \exp(-c/\kappa)] = 4$

or equivalently

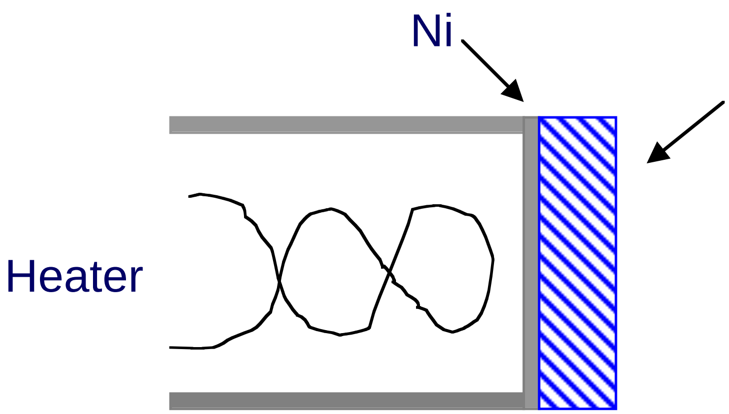
$\Phi = 2.65 + 2.9 \times 10^{-4}\,T$

	A_o	Φ_o
Th-W	**4**	**2.65**

	T	Φ	J(A/cm^2)
Th-W	**1950K**	**3.22**	**2.2**
	2150K	**3.27**	**12.0**

Oxide Cathodes

	Φ (eV)	T (K)	J (A/cm^2)
W	4.6	2608	1
Th-W	3.2	1870	1
Oxide	1.5	942	1



BaO, SrO, CaO
Standard ASTM mixture
49%, 44%, 7% (atomic %)

Nickel substrate:

Active Ni, Ni with impurities such as W

Φ = 1.5 eV

Passive Ni, Ni without active impurity

Φ = 1.85 eV

Preparation and Processing of Oxide Cathodes

Sprayed method:

$BaCO_3$, $CaCO_3$ and $SrCO_3$ are dissolved in organic solvent. After mixing thoroughly, the solution is sprayed onto nickel substrates.

Applied method (Sarong cathode)

$BaCO_3$, $CaCO_3$ and $SrCO_3$ in organic binder forms a self-supporting sheet. Disks are cut from the sheet and applied to nickel substrate.

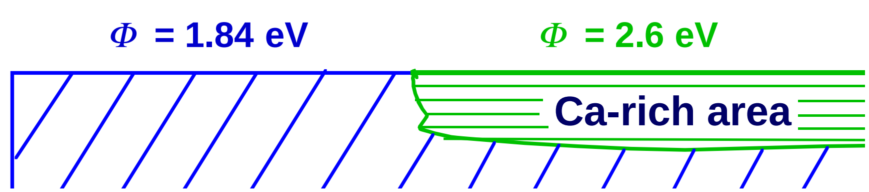
Potential problem:

Copious gas release during the initial cathode heating.

$$\left.\begin{array}{l} 2\,BaCO3 \longrightarrow BaO \cdot BaCO_3 + CO_2\uparrow \\ BaO \cdot BaCO_3 \longrightarrow 2\,BaO + CO_2\uparrow \end{array}\right\} \quad T = 800^oC$$

Melting temperature of the eutectic basic barium carbonate , $BaO \cdot BaCO_3$, occurs at about 900ºC.

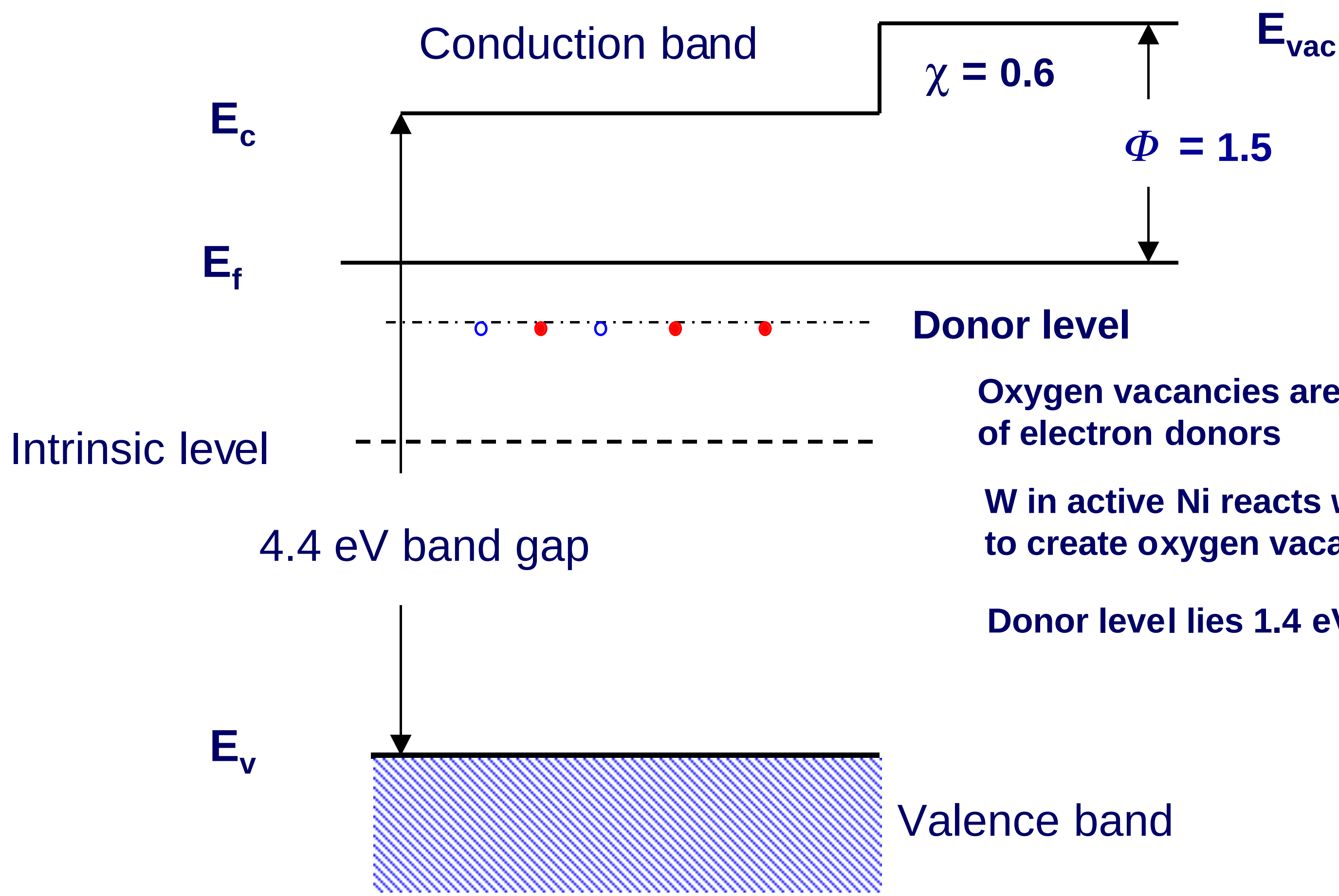
If this melting occurs CaO can segregate to the surface.



Reference: Shih and Haas, Appl.Surface Sci. 2(1979)164

Work Function of Oxide Coating

Band diagram of BaO



Oxygen vacancies are sources of electron donors

W in active Ni reacts with O in BaO to create oxygen vacancies.

Donor level lies 1.4 eV below E_c

Reference: Haas and Shih, Appl. Surface Sci. 8(1981) 145

Properties of Oxide Cathodes

Activation mechanism:

Generation of oxygen vacancies,

which shifts E_f from the intrinsic level to above the donor level

Φ = 1.5 with active Ni substrate

Φ = 1.85 with passive Ni substrate

Poisoning mechanism:

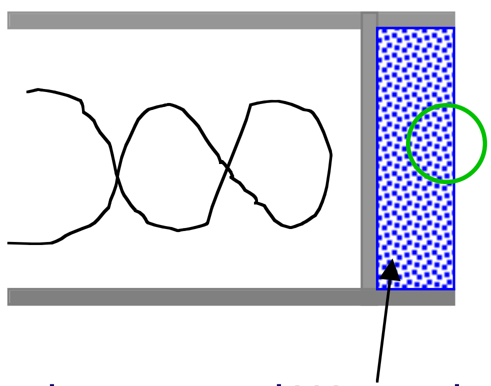
Annihilation of oxygen vacancies.

Poisoning gases: O_2, CO_2, H_2O and S.

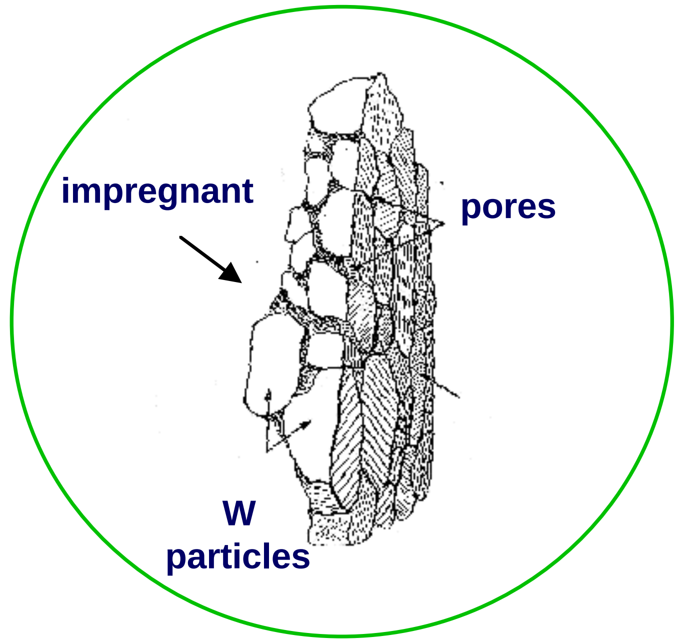
Disadvantage of oxide cathodes:

- Not robust against residual gas poisoning.
- Coating flakes off after air exposure.
- Low D.C. emission, < = 1 A/cm².

Standard Dispenser Cathodes



Matrix : pressed W powder
20% porocity



Impregnant:

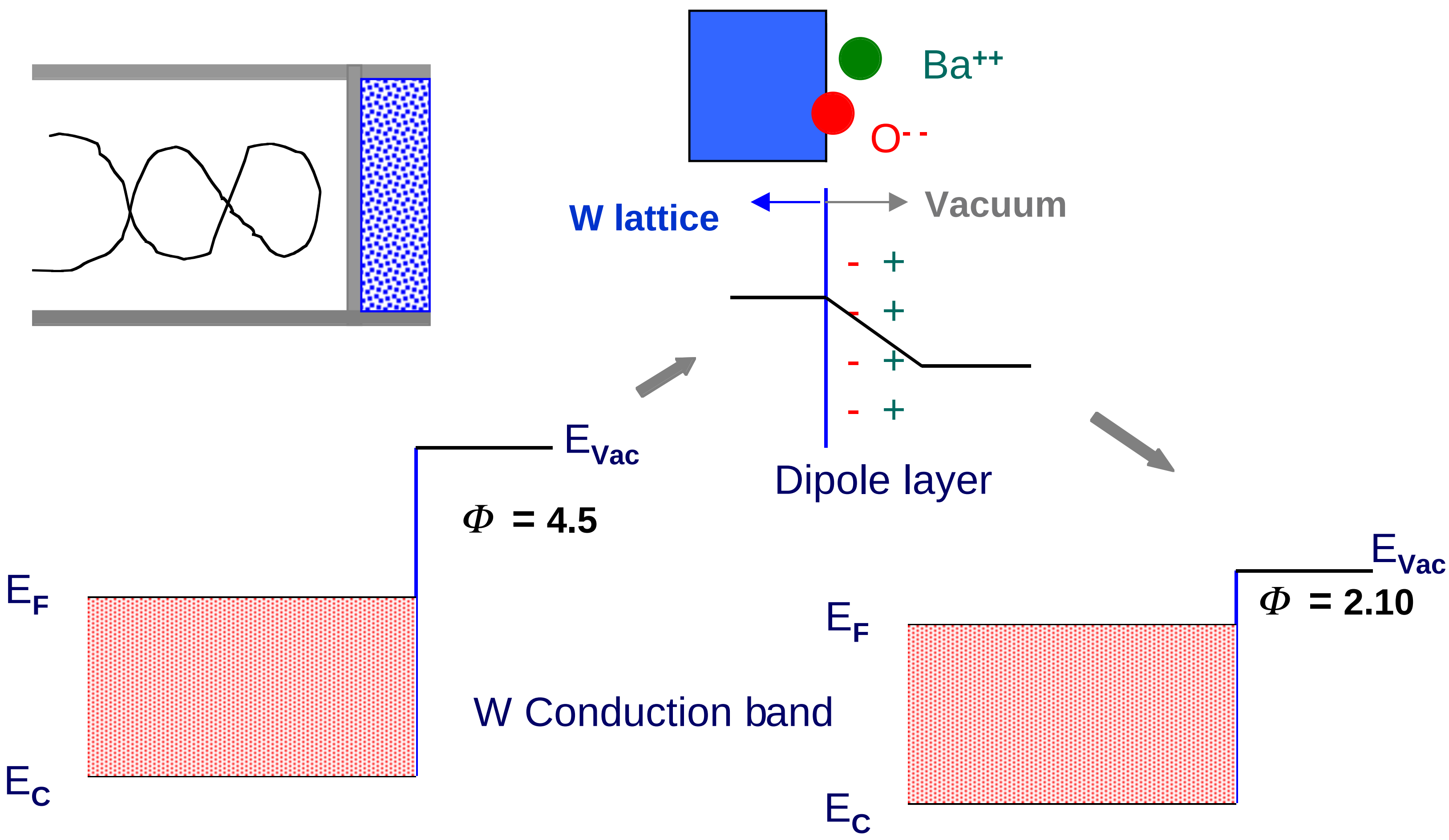
4BaO, CaO, Al_2O_3 : [411], S-type

5BaO, 3CaO,2Al_2O_3 : [532], B-type

W provides the electrical conductivity.

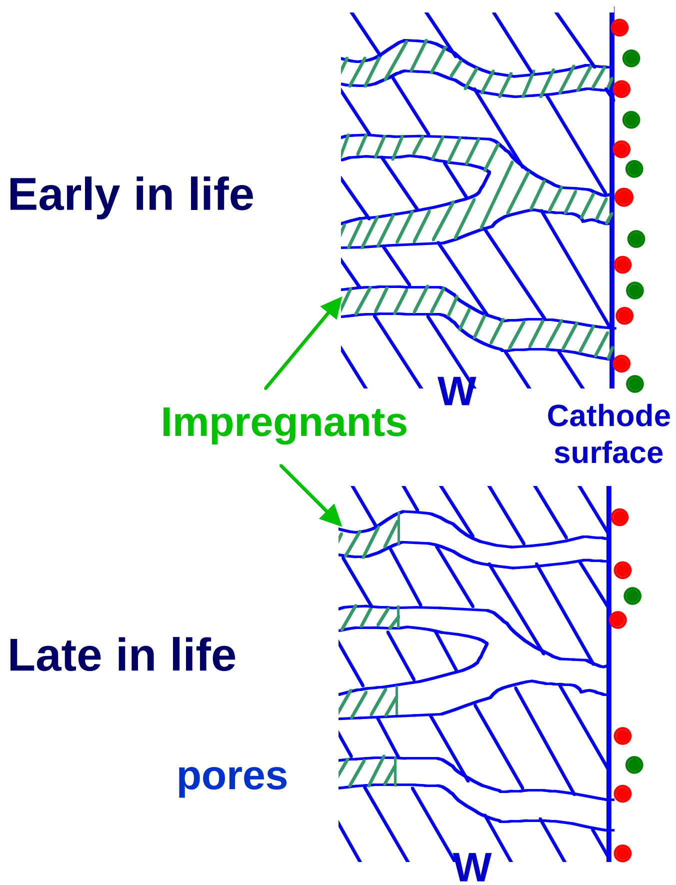
BaO lowers Φ .

Work Function of a Dispenser Cathode



Cathode Surface Changes with Life

Cross-sectional view



Early in life, almost a full layer of Ba and O on the cathode surface.

During operation, desorption of Ba occurs, but a supply of Ba from the pores maintains a full coverage on the surface.

Impregnants near the pore end depletes during life, resulting in low surface Ba coverage and poor emission.

Properties of Dispenser Cathodes

Cathode poisoning:

CO_2, O_2 or H_2O adsorption reduces dipole effect
CO, CH_4, H_2 or N_2 adsorption does no harm,
but C residue poisons cathodes.

Reactivation from poisoning:

Thermal desorption of the poisoning gases.

Impregnant replenishes the surface Ba.

Compared to oxide cathodes:

More robust against gas poisoning.
Reusable after air exposures.

No DC emission limitation.

Higher work function.

	Φ (eV)	**T (J =1 A/cm^2)**
Oxide	1.5	942 K
Standard	2.1	1277 K
Os-coated	1.95	1194 K

Modification of Dispenser Cathodes

Coating: Strengthening the dipole

	Φ **(eV)**
Os-coating (M-type)	1.95
Os-W alloy-coating	~1.85
Ir-W alloy-coating	~1.85

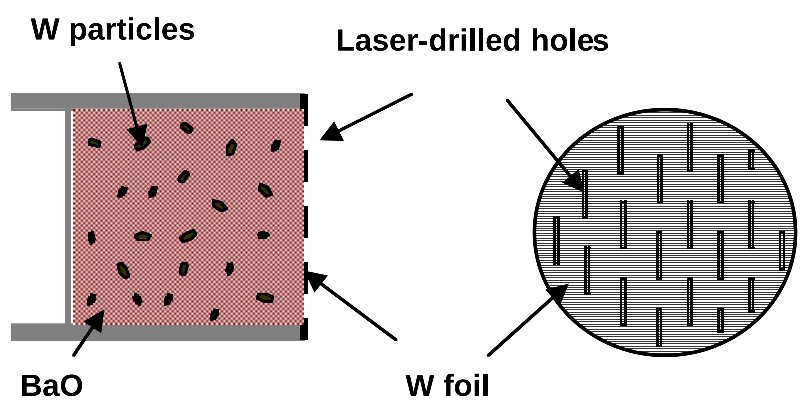
Structure: Improve life or uniformity

Reservoir of Ba: **RV cathodes**

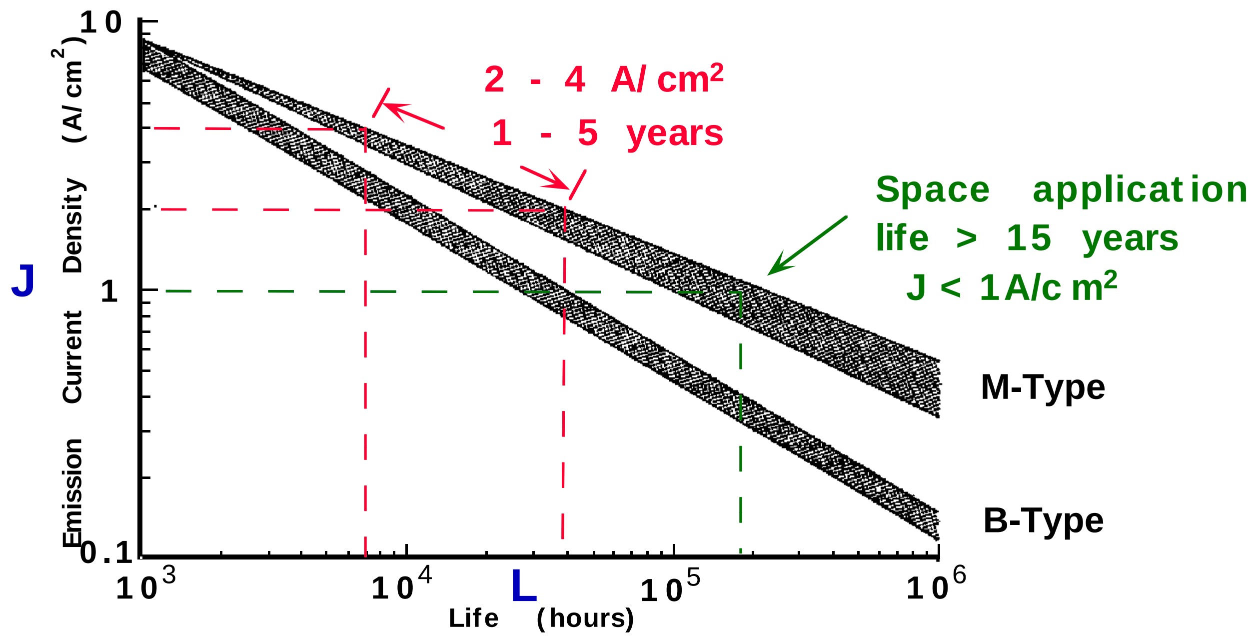
Long life

Controlled pores: **CPD cathodes**

Uniform emission



Trade-off between life and J



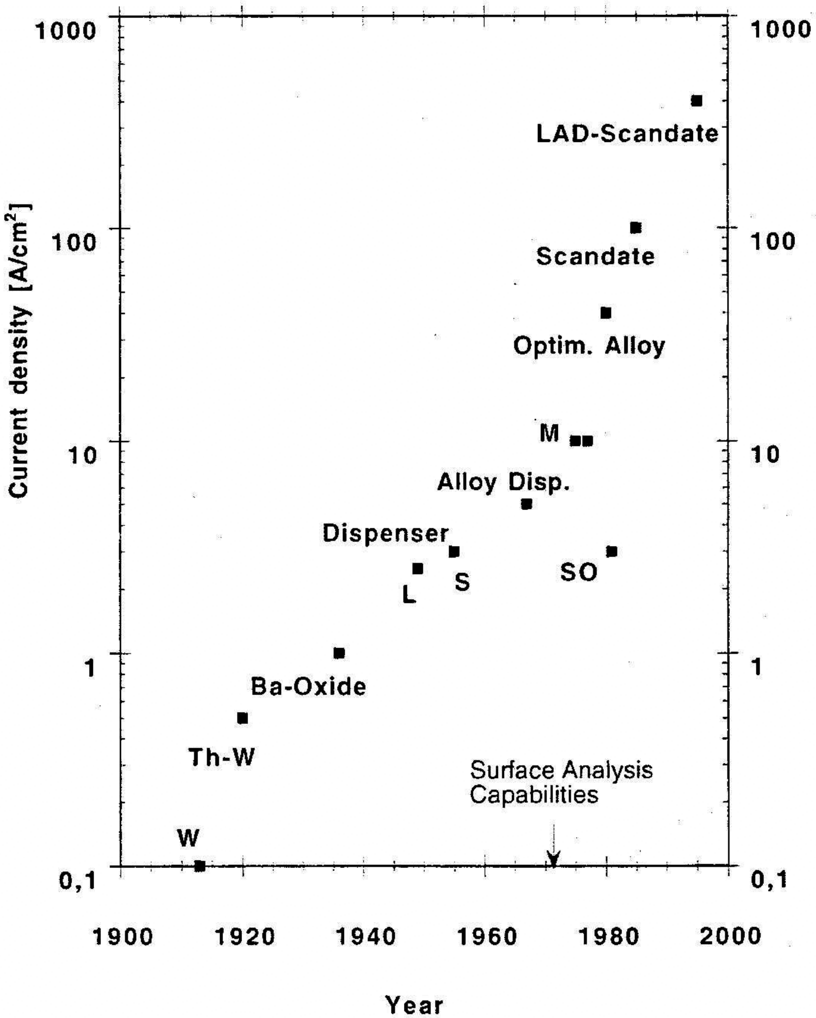
A.S.Gilmour,"Microwave Tubes", p132, (1986) Artech House, Inc.

Life test at very high J:

B-cathode: 45 A/cm^2, 50 hours at 1620K, LLNL

R.E.Thomas et al, IEEE Trans on Electron Devices 37,no.3 (1990) 850.

Historical Development of Thermionic Cathode Emission Capability



G.Gartner et al, Appl. Surface Sci 111 (1997) 11.

	Φ
Standard dispenser	2.15 eV
M-type	1.95 eV
Optimum Alloy	1.85 eV
the best Scandate	1.47 eV

Philips Research Lab claims: 400 A/cm^2 at 1300 K

Emission capability of a cathode with Φ =1.47 eV

T (K)	T(^{o}C)	J (A/cm^2)
1300	1030	400
1200	930	115
1100	830	26
1000	730	4.6

Scandate Cathodes Are Not Yet Available

Practical issues:

Unavailable commercially.

Fabrication technique needs to be developed.

Philips Research Lab. Provided little information.

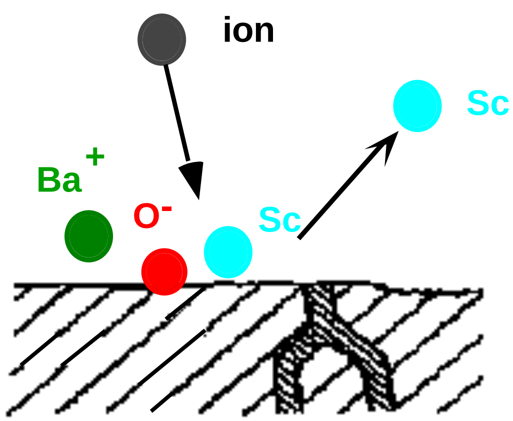
Fundamental issues:

1. Robustness in practical environment.

2. Emission uniformity.

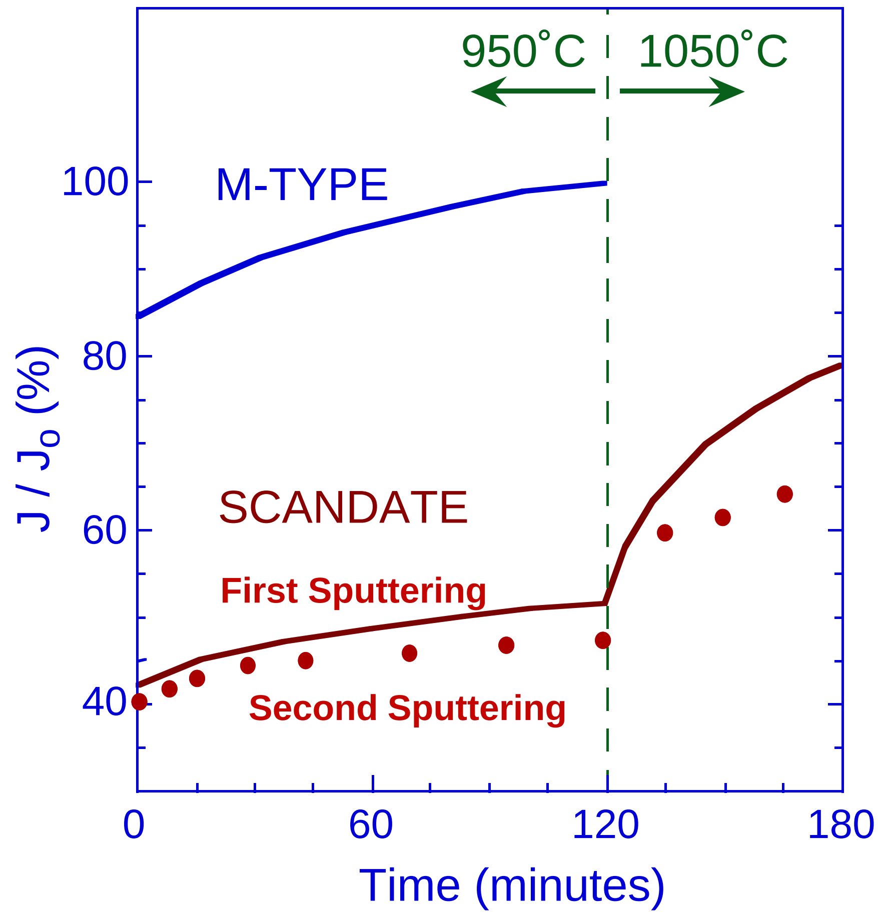
Slow Emission Recovery from Ion Beam Damage

Cathode in Tube Environment:



Ion Bombardment Removes Sc

⇒ Sc Needs to be Replenished



J. Hasker et al Appl. Surface. Sci. 26(1986) 173

Scandate Emission Characteristics

Dispenser Cathodes (e.g. M-Type):

- **Observe emission "saturation"**
- **Surface emission model (uniform ϕ)**

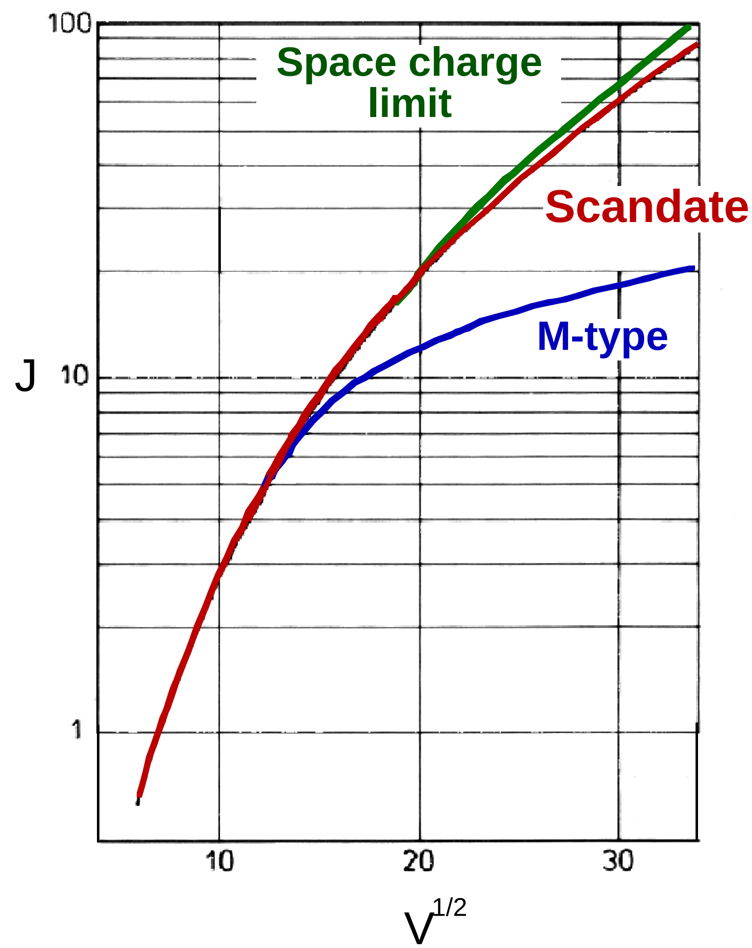
Scandate Cathodes

- **Emission continues to rise**
- **Emission model: unknown**

Two Possible Models:

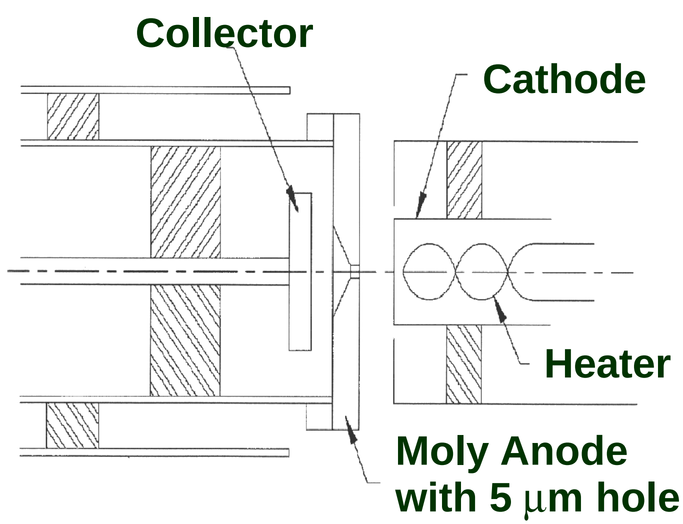
1. Semiconductor Emission Model
$\rightarrow$ Uniform emission

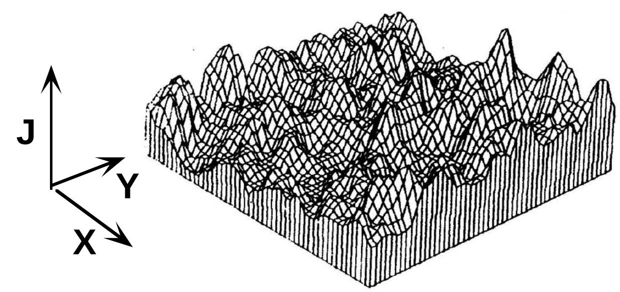
2. "Patchy" Surface Emission Model
$\rightarrow$ Higher J but non-uniform emission



Emission Uniformity Measurement Technique

Scanning Anode Probe





Emission Mapping

Fabrication Methods of Scandate Cathode

Scandate cathode types	J (T=1300 K)
Pressed W + $Ba_3Sc_4O_9$	5 - 10 A/cm^2
Sc in the impregnant	20 A/cm^2
Top-layer types	
Mixed powder	100 A/cm^2
Sputtered	35 - 80 A/cm^2
Pulsed Laser Deposition (or Laser Ablation)	400 A/cm^2